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LIMING THE SOIL

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Two thousand years ago, the Romans knew that lime increased the productiveness of many soils, and now lime is one of the most frequently advised soil amendments. In the humid parts of the United States, lime is much more frequently advantageous than in California. The soils of this state, in most places, are well supplied with lime, yet it is found very helpful under certain conditions on some soils.

Today the progressive farmer would like to have answers to many questions, such as the following, in regard to the use of lime:

Why do some soils need lime while others do not?

Does this soil need lime?

Will it pay to use lime on this soil?

How is it possible to find out what will be the effect of lime on this soil?

What becomes of lime after it is applied to the soil?

How is lime lost from the soil?

What kind of lime is best?

Which form is cheapest?

Where can lime be obtained?

How may one find out the quality of a sample of lime?

It is the purpose of this circular to answer these and other questions, as well as possible in the light of present scientific and practical knowledge. Also, some suggestions will be made.

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* Credit is due the several members of the staff of the College of Agriculture who have given constructive criticisms during the preparation of this circular.

I. GENERAL STATEMENTS AND EXPLANATIONS

In everyday, common language, the word "lime" may mean any one of a number of substances which are sometimes used for soil improvement, and "liming" means the use of some one or more of these materials on the soil. In a strictly technical sense, only calcium oxide (CaO) (quicklime), or calcium hydroxide ($Ca(OH)_2$) (slaked lime) may be properly spoken of as lime. For the present purpose, the word "lime" will be used in the ordinary sense, meaning any one of several compounds of calcium used as soil amendments. Gypsum is not to be considered as a liming material, although it does contain the element calcium, and is often of great value as a soil improver.

Why soils need lime.—It is common knowledge that *some* soils need, or are improved by lime, and that lime applied at one time may, after a while, become ineffective. Nearly all natural waters contain lime which has been dissolved out of the rocks or soil over which the water has passed. In this way, the soil gradually loses its lime, which is usually carried to the ocean, where it is deposited and becomes limestone. By this process have originated most of our limestone deposits now used in industry and agriculture. In arid regions where there is little leaching by rain, there is usually plenty of lime in the soil, but where rainfall is heavy, it is likely to be deficient. At Ithaca, New York, the loss of lime by leaching has been found to be as much as 1000 pounds an acre a year, and similar losses have been observed in other places.

All agricultural crops absorb lime so that the soil is gradually depleted of this material by the ordinary removal of crops from the land. However, the amount of lime thus carried away is small compared to that commonly lost by leaching.

Some fertilizers, for example, sodium nitrate, ammonium sulfate, and acid phosphate, tend to increase this loss. Others, such as bone meal, calcium cyanamid, basic slag and ordinary manures, increase the supply. The greater the quantity of lime applied to the soil at any one time, the more rapid will be its loss in the drainage water.

Soils which have become deficient in lime are frequently called sour or acid. But perhaps the undesirable properties of the so-called sour soils are more frequently due to a lack of lime than to the presence of injurious acids. Again, some acid soils may contain sufficient lime, but are infertile from some other cause. Certain acid bog soils have been greatly improved in productiveness by the addition

of phosphates which seem to produce their desirable effect, not by neutralizing acid or by supplying phosphate as fertilizer, but by chemically removing from the soil moisture poisonous aluminum which hinders the growth of crops. Nevertheless, in most cases, all of the evils which may be included under the term ''sour soil'' are cured by lime.

How lime is retained in the soil.—When lime in any form is applied to the soil, it is probable that some of it is soon converted into silicates, the rest into carbonate. The latter is readily dissolved and carried away by the water percolating through the soil, while the silicates of lime are much more durable in the soil, though they also are slowly dissolved and washed away. Some lime is combined with the humus or organic matter in the soil.

How lime is moved about in the soil.—Unless it is dissolved by water, lime moves very little in the soil. Heavy applications to the surface soil have not penetrated below one foot in many years, that is, the amount of lime in the subsoil is not much increased by applications to the surface. When the lime is dissolved by water, however, it is usually carried along as far as the water goes, commonly into the drainage and thus is lost to the land. There is one exception common in countries of low rainfall. When the rainwater does not penetrate far enough to get into the drainage, the dissolved lime is likely to be deposited again in a layer at the lowest point to which the water penetrates. If this process is repeated many times in the course of years, the soil materials at this point become cemented together by the lime carbonate and silicate, and a lime hardpan is formed. When once formed, the hardpan is likely to remain intact, unless it is brought to the surface where it may weather down into soil once more.

Kinds of soils improved by lime.—Practically all kinds of clayey or heavy soils which do not contain much lime are more or less benefited by lime, and loams or sands having little lime are usually improved by liming. Commonly, but not always, acid soils are improved by lime. There are many methods of testing soils to determine their so-called ''lime requirement,'' but none of them are always reliable. Experience is the only sure guide to show whether or not lime will be beneficial.

Indications of plenty or lack of lime in the soil.—Hard well water is usually a good indication of plenty of lime in the soil, while soft water is commonly found when lime is deficient. Many leguminous plants, such as alfalfa and clover, grow well in soils well supplied

with lime but not in soils deficient in lime. Sorrell and sour dock grow well in the absence of lime, but also may prosper in well-limed soil.

Only an actual field trial can show with certainty whether it will pay to use lime. For this reason, it is important that any one who is uncertain as to the value of lime on his land should first confer with the local farm advisor. The latter is likely to know whether lime will probably be a paying investment on the soils of his locality, and will give specific advice about how and when to apply it. The final proof of the value of lime on the soil is found in an increased yield of clover or alfalfa, or of some other crop in the rotation. Perhaps it may be merely an improvement in the ease of tillage and in general betterment of the physical condition of a heavy soil. It is sometimes found, however, that the gain in increased crops or in ease of tillage does not equal the cost of liming.

Lime is not a fertilizer.—Natural limestones in many cases have been partly derived from decomposition of animal remains, so that in consequence the limestone contains a small amount of the nitrogen and phosphorus of the animal. However, the amount of these plant foods remaining in the limestone usually is so small that it is of little value. Nevertheless, some ill-informed dealers may present to their prospective customer a chemical analysis showing that the lime they sell contains nitrogen, phosphorus, and potash, and they argue that it is a true and valuable fertilizer. The percentage of these plant foods in most limestones is probably less than in good fertile soils. *Limestone or other lime material is valuable in agriculture almost solely for its lime content.*

Experience has shown that the value of lime is usually increased by the use of fertilizers, and also that fertilizers are most effective when lime is adequate. The reason for this is evident. Anything that increases the crop produced on a given soil increases the draft of the crop on the plant nutrients in the soil, thus tending to exhaust the soil more rapidly. Consequently, to obtain the greatest value from fertilizers, lime should be adequate, and the greatest benefit from lime is received when the soil is well fertilized.

II. EFFECTS OF LIME ON THE SOIL

Ordinary fertile soil is composed chiefly of three classes of substances, besides water—mineral, organic, and biological. The mineral part consists mainly of rock fragments with powdered rock and clay. The organic portion is merely the remains of plants and animals. Though small in amount, this portion is a very important part of a good soil. The biological part of the soil is also very essential. It consists of the microscopic organisms (bacteria, protozoa, molds, etc.), also insects, worms and small animals. In a moist soil, all these various parts are surrounded or covered by a film of water which is commonly spoken of as the "soil solution." In the soil solution are dissolved small amounts of many chemical substances known as salts, which provide the mineral elements essential for plant growth. When lime is added to soil, it may cause changes in each of the three chief components, the mineral, the organic, and the biological.

Physical changes in soil produced by liming.—Clay is flocculated so that a number of the small particles become united into a single larger one. This results in improvement of the crumb structure, and in the lightening of heavy soils so that clay becomes less sticky and easier to work, more easily penetrated by water and better drained, and hence the available capillary moisture is increased. This tends to lengthen the growing season for crops, and makes injury from drought less probable. Usually it may be taken for granted without any kind of tests that heavy, sticky soils will be physically improved by liming so that the growing season of crops will be lengthened, the expense of cultivation reduced and the productiveness of the soil increased. All these tend to increase the money value of the land. It is reported that, at the Rothamstead Experimental Station in England, liming a heavy soil reduced the draft in plowing 16 per cent and increased the speed of traversing the field 26 per cent. In other cases, it appears that improvement in ease of tillage of heavy soils produced by liming has more than paid for the cost of treatment by a reduction in the cost of cultivation.

Sandy soils are improved in water-holding capacity by liming. When a very great amount of lime is added to a heavy soil, its physical condition is profoundly changed so that it no longer retains its clayey character. Sands also are greatly modified by addition of large amounts of lime so that they become similar to heavy soils which contain much lime. A soil which contains much lime is called a marl, or a marly clay or a marly sandy soil.

The chemical changes in soil caused by lime are commonly called "sweetening." Soil acids are neutralized and harmful conditions frequently associated with these acids are avoided. When the soil contains sufficient lime to make it neutral or slightly alkaline, salts of iron, aluminum and manganese cannot dissolve in the soil solution in amounts sufficient to be poisonous to plants. Under these conditions, also, the phosphorus of added fertilizers is less likely to form unavailable compounds with aluminum or iron.

A desirable exchange of bases in the soil zeolites (a clay-like portion of the soil) is sometimes promoted by lime, so that lime is absorbed and potassium is released for the nutrition of plants. Whether this change is of much practical value is still an unsettled question.

Deflocculation and running together of clay, which may occur in the absence of lime, is prevented by plenty of lime. Deflocculation means the breaking up of the compound soil crumbs into the much smaller particles of clay. These very fine particles are what give clay its "clayey" character.

All forms of lime have finally much the same effect on soils, but when first applied there is some difference between the effects of caustic and of carbonate forms. The caustic or quicklime forms are much more soluble in water and therefore produce their effects on the soil much more quickly than the carbonate of lime which is but slightly soluble in water. Consequently some form of caustic lime is preferred when it is desired to improve a clay soil quickly, although carbonate forms of lime, when ground very fine, act almost as rapidly as caustic lime. The somewhat common belief that the use of quicklime on the soil causes more rapid destruction of organic matter than carbonate of lime, has been shown to have little foundation in fact.

Alkali soils may be affected in two quite different ways by lime. In the presence of much white alkali (sodium salts) lime sometimes causes formation of the very injurious black alkali. When, however, a soil contains black alkali with only a little white alkali, lime, together with decaying vegetable matter, tends slowly to neutralize and remove the black alkali. For overcoming black alkali, however, gypsum is much more effective than lime.

Biological effects of liming.—Fertile soils harbor vast numbers of bacteria and other micro-organisms which subsist on the vegetable and animal substances in the soil, changing them so that crop plants can obtain nutriment from them. This decomposition process is commonly spoken of as "production of humus." Insufficient lime favors

the growth of objectionable bacteria which produce undesirable or poisonous products. Plenty of lime favors the growth of desirable bacteria and this growth causes changes which benefit crop plants by accelerating oxidation of organic matter and destroying poisonous substances.

The two most important of these changes are ammonification, by which the nitrogen in organic materials is changed into ammonia; and nitrification, the change by which ammonia is converted to nitrate, the form in which most plants take up their nitrogen. Fixation of nitrogen from the air so that it becomes available to plants, also requires lime in the soil to make conditions suitable for nitrogen-fixing (symbiotic) bacteria.

On the other hand some undesirable organisms of the soil are favored by plenty of lime. Such is the fungus which causes potato scab. This potato disease is much less injurious in an acid soil. Excessive lime favors ''root rot'' of tobacco, a fungous disease, but it reduces activity of another fungus, the ''finger and toe disease'' of cabbage and similar plants.

Lime is an essential element in plant nutrition. For this need, most soils probably contain enough lime. Too much lime in some of our California soils is associated with a diseased condition known as chlorosis which affects certain plants. No satisfactory treatment of soil for this trouble is known. Probably it is rarely or never caused by artificial addition of lime.

Experiments have shown that plants grown with plenty of lime in the soil are much richer in lime than those grown in soils where lime is deficient. A deficiency of lime in plants, such as alfalfa, seems to be caused by the presence of black alkali in the soil, so that although the soil may contain much lime, it is not available to the plant. Experiments are being conducted to find a method of correcting such conditions.

III. EFFECT ON CROPS OF LIMING THE SOIL

Besides the already mentioned more or less indirect effects on plants which are caused by liming the soil, some more direct effects must be considered. Some plants grow much better in the presence of plenty of lime, others succeed better in acid soils. In the former class are the legumes such as alfalfa, red and white clover, soy beans, peas, alsike clover, cowpeas, vetch and field beans. Blueberries, watermelons, rhododendrons, and cranberries, on the contrary, seem to be injured by soil conditions associated with large quantities of lime.

IV. FORMS OF LIME* FOR AGRICULTURAL USE

The better grades of lime materials are likely to be used in trade and industry, leaving for agricultural use only the poorer grades which vary greatly in purity.

The substances other than lime contained in the low grade materials are usually of little value in the soil. The three principal forms of lime materials as regards chemical composition, are oxide, hydrate, and carbonate.

The carbonate form is found naturally as marble, limestone rock, marl (which is unconsolidated limestone mixed with more or less clay and sand), shells (such as those of oysters or clams), or as by-products of manufacturing such as air-slaked lime, sugar factory waste lime, and ashes of some kinds. All of the carbonate forms are relatively inert and may be applied to the soil in almost any amount without direct injury to plants.

The oxide and hydrate of lime are commonly spoken of as caustic limes. They may cause temporary injury to vegetation if applied to growing plants in large quantities. After some days or perhaps weeks in the soil, however, the caustic forms become converted to carbonate or silicate, thus losing their caustic properties. Caustic lime is the ordinary lime used in building, known as burnt, lump, or quicklime. It is made by burning carbonate of lime at red heat, whereby the carbon dioxide or carbonic acid of the carbonate is driven off and calcium oxide, oxide of lime, remains. When exposed to the air, the oxide or hydrate takes up carbon dioxide from the air and again becomes carbonate, which is then known as air-slaked lime.

Hydrated lime is made by adding to quicklime somewhat less than half its weight of water. The water is taken into chemical combination with the lime and the lumps of quicklime fall to a fine dry powder, hydrated lime. This form of lime, mixed with uncombined water, is found in various waste products, such as acetylene waste lime from carbide gas generators, tannery waste lime and gas-house waste lime. Acetylene waste lime and gas-house waste lime are likely to contain poisonous substances which are injurious to plants. For this reason, these limes should not be used on the soil at a time when tender plants are growing. After these limes have been exposed to the air and moisture in the soil, the poisonous substances disappear. Then the lime is as good as an equivalent amount of any other lime.

* In this discussion, gypsum is not regarded as a lime material.

Magnesium limes are any one of the above-mentioned forms which contain more or less magnesium. Natural magnesium limestone is called dolomite. Magnesium limes are usually equal or greater in value agriculturally than pure limes, except that their action is slower.

Phosphates of lime, such as bone meal, basic slag, and lime-nitrogen, or calcium cyanamide, have some value as lime materials, in addition to their content of phosphate or nitrogen to which they owe their chief value. Still another form of lime which has some agricultural value is the silicate which is a component of many natural rocks. It is not an ordinary article of commerce, but may be made artificially.

TABLE 1*

APPROXIMATE QUANTITIES OF TOTAL AND AVAILABLE OXIDES OF LIME IN ONE TON OF LIMING MATERIAL

Market material	Total oxides		Available oxides	
	Per cent	Pounds (per ton)	Per cent	Pounds (per ton)
Limestone, fine, 1/60 in. mesh	52	1040	100	1040
Limestone, fine, 1/60 in. mesh, impure	45	920	100	920
Limestone, coarse, 1/8 in. mesh	52	1040	50	520
Gas house lime	35	700	50	350
Beet sugar lime	39	780	100	780
Lump lime, pure	98	1960	90	1764
Lump lime, impure	85	1700	70	1190
Quick lime, ground	90	1800	96	1728
Hydrated lime	75	1500	100	1500

* Data from National Lime Assn., Trade Bul. 102, Washington, D. C.

All of the forms of lime differ greatly in value, because of the varying degrees of purity of the natural rock from which they are derived. Also, the amount of water in the hydrated forms varies greatly so that they do not have any very definite composition. The most practical measure of value of lime is its power of neutralizing acids. When quite pure, 56 pounds of oxide, 74 pounds of hydrate and 100 pounds of carbonate have equal neutralizing powers. Or, roughly, one ton of carbonate is equalled by three-quarters of a ton of hydrate, or one-half ton of oxide of lime. Table 1 shows the relative lime value of different liming materials.

Importance of fineness.—The agricultural availability or effectiveness of the various forms of lime is largely dependent on the purity

and fineness of the particles. The purer and the finer the lime the more rapidly will it act. Very impure lime is slow to react with the soil acids, besides having deficient liming power. The coarser the particles of the lime material, the less easily will it become thoroughly mixed with the soil, the slower will be its action and also the longer will it last. Limestone particles of from 10 to 20 mesh size may last for 10 years in the soil without producing much effect. Such material cannot be considered as available lime.

Ground limestone which will pass a 60-mesh sieve is fine enough to be almost as effective as the caustic forms. The latter are extremely fine by reason of the method of their preparation. Sugar house waste lime is peculiarly well adapted to agricultural use on account of its extreme fineness. It is one of the carbonate forms of lime. It also contains small amounts of nitrogen, potash and phosphorus, so that it acts to a small extent as a fertilizer as well as a lime material.

For equal neutralizing effect, there is considerable difference in cost between the various forms of lime and this difference will vary with the locality. Since the value of a lime material is best measured by its power to neutralize soil acids, the farmer should endeavor to buy that form which will supply the most neutralizing power to his soil for a dollar.

To determine which form will give the most for the money, it is necessary to know the cost of (1) a unit of lime at the plant or the dealers, (2) freight, (3) wagon haul, and, (4) spreading. The cost of (1) may not be the chief cost. The cost of (2), (3) and (4) may be reducd by using higher purity or more concentrated forms. Hauling cost (3) may be a large proportion of the total. It may run from 50 cents a ton for one mile, up to three dollars a ton for ten miles. An ordinary case might be as follows, for one application of two tons ground limestone per acre:

First cost, including freight, two tons @ $3.50 per ton	$7.00
Wagon haul, five miles	3.20
Spreading on the land	1.05
Total cost per acre	$11.25

The following table gives a more complete statement of estimated items of costs of liming materials delivered on the farm.

When this method of computation is employed, results often surprising to the farmer are secured. Indeed, the material that appeared cheapest to him based upon the quotation at the factory or at the station, may often prove to be comparatively expensive.

TABLE 2†

FACTORS OF COST OF LIME DELIVERED AT THE FARM

	Cost at kiln or mill in bulk	Cost of bagging or extra handling	Expense of freight 100 miles	Expense of wagon haul 6 miles	Approximate total cost at farm	
					Per gross ton	Per 100 lbs. of available oxides
Limestone, fine, 1/60 in. mesh	$3.50	$1.75	$1.40	$2.50	$9.16	$0.880
Limestone, fine, 1/60 in. mesh, impure	2.75	1.75	1.40	2.50	8.40	0.913
Limestone, coarse, 1/8 in. mesh	2.00	1.75	1.40	2.50	7.65	1.471
Gas house lime	.50	1.00	1.40	2.50	5.40	1.543
Lump lime, pure	8.50	2.50*	1.75	2.50	15.25	0.865
Lump lime, impure	6.00	2.50*	1.75	2.50	12.75	1.071
Quicklime, ground	8.00	2.00	1.75	2.50	14.25	0.825
Hydrated lime	10.00	2.50	1.75	2.50	16.75	1.116

* Fifty cents allowed for slaking.

† From National Lime Assn., Trade Bul. 102, Washington, D. C.

These figures are not to be regarded as actual costs since they will vary widely, depending on local conditions, but rather as approximate values used to illustrate the method of computation and which may be substituted by actual costs. They indicate rather the method of calculating the cost for any form of liming material, and enable the buyer to figure in which form he can get the most lime value for his money. The retail price of ground limestone at the dealers may vary from one to ten dollars per ton at different places in California. The market price evidently cannot be considered as a measure of value of the material on the farm. Since the acid neutralizing power of various forms of lime of different degrees of purity varies so greatly, it would seem best to buy lime material by the unit (which is 1 per cent of a ton or 20 lbs.) of oxide of lime rather than by the ton or other unit of weight.

V. SOURCES OF AGRICULTURAL LIMESTONE

The three chief sources through which ground limestone may be secured are the regular dealers, the farmers' association and the individual farmer. When demand is small, the regular dealer will supply it at a profit to himself and usually at a relatively high price.

The following is a list of the chief dealers in lime in California:

REGISTERED DEALERS IN AGRICULTURAL LIME, FOR THE FISCAL YEAR ENDING JUNE 30, 1925

(From Special Publication No. 52, Department of Agriculture, State of California, on Commercial Fertilizers, Agricultural Minerals, 1924.)

Agricultural Lime and Compost Company, 485 California street, San Francisco, Calif.

Bernal Marl Fertilizer Company, 207 South First street, San Jose, Calif.

A. M. Blumer, 433 California street, San Francisco, Calif.

California Associate Buyers Company, 153 Broadway, Fresno, Calif.

California Lime Company, Fortieth and Opal streets, Oakland, Calif.

California Portland Cement Company, 1228 Pacific Mutual Building, Los Angeles, Calif.

El Dorado Lime and Minerals Company, Shingle, Calif.

E–Z–Way Company, 955 Sixty-first street, Oakland, Calif.

Grand Canyon Lime and Cement Company, 840 Commercial street, Los Angeles, Calif.

Holmes Lime and Cement Company, 2 Pine street, San Francisco, Calif.

Horton Lime Company, 681 Market street, San Francisco, Calif.

Kaweah Quarries, Lemon Cove, Calif.

Arthur F. Levitt, 411 South Main street, Los Angeles, Calif.

H. B. Matthews, 466 Jackson street, Pasadena, Calif.

Mount Diablo Lime Marl Company, Walnut Creek, Calif.

Nevada Lime and Rock Company, 846 Commercial street, Los Angeles, Calif.

Nitrate Fertilizer Company, 754 South Maple street, Los Angeles, Calif.

Pacific Guano and Fertilizer Company, Matson Building, San Francisco, Calif.

Pacific Lime and Plaster Company, 58 Sutter street, San Francisco, Calif.

Pacific Limestone Products Company, 25 King street, Santa Cruz, Calif.

Pacific Portland Cement Company, Consolidated, 827 Pacific Building, San Francisco, Calif.

Pennewell and Company, Lemon Cove, Calif.

Pep Chemical Company, Alameda and Southern Pacific tracks, Burbank, Calif.

Torrance Lime and Fertilizer Company, 301 Bradbury Building, Los Angeles, Calif.

Union Lime Company, 3220 San Fernando road, Los Angeles, Calif.

Farmers' associations in some places have been able to supply their members with ground limestone at much lower cost than dealers' prices. These associations are formed where there is a demand for considerable lime. They set up a plant for grinding limestone which is usually obtained from some local quarry. Thus, if the association is well managed, the members will get their limestone at the lowest possible cost. By arranging so that all do not want the lime delivered at the same time, a relatively small plant may be able to supply a large amount of material. Some of the ground limestone could be stored during times when farmers were busy with other work, so that when the demand for lime is great it could be quickly supplied. One successful plan consists in using a portable grinder which can be taken to the place where lime is wanted. The individual farmer may, in some cases, have his own outfit for supplying his own needs, and perhaps those of some of his neighbors.

Perhaps one of the main reasons why lime is not more frequently used on the soil is that it is not a retail commodity which can always be obtained in any amount when it is wanted. If it could be had more cheaply and conveniently, probably much more lime would be used.

VI. APPLICATION OF LIME TO THE SOIL

At what time should lime be supplied to the soil?—So far as the soil is concerned, it makes little difference when lime is applied. Caustic lime should not be applied while any tender crop is growing. Otherwise, lime may be applied at any time when it is most convenient. Since the lime must be well worked into the soil to produce the desired effect, it is evident that this can be done best on plowed ground so that the lime will be stirred into the soil by harrowing. On meadows or pastures, lime may be spread on top of the ground, probably most advantageously during the winter when the grass is not growing much.

How lime may be spread on the soil.—One common way is to throw it by shovels from a wagon as it is driven across the field. This is likely to result in uneven application. A better method is to distribute lime from a machine somewhat like a grain drill, which makes a uniform application. Such machines may be bought of dealers or contrived from materials on the farm.

Amount of lime to be used.—In the past, large applications at one time have been recommended, enough to completely neutralize the

soil acidity. Now it is known that it is not necessary to neutralize all the soil acidity, so that smaller and more frequent applications are more economical and perhaps more effective. On any but the most acid soils, 500 pounds an acre every year or two is likely to be sufficient. Since some crops need less lime than others, the lime should be used just prior to that crop in the rotation which needs the most lime. As a general statement, it may be said that enough lime should be used so that it is never a limiting factor in crop production, provided that the cost is not greater than the value of increased crops produced. If, however, the lime is used to improve the texture of a heavy soil, much larger amounts may be needed to produce the desired effect.

A New Jersey example shows the economic advantage of light over heavy liming. During a 15-year test, one-half ton of ground limestone to the acre annually yielded the same crop increase as an application of two tons to the acre. That is, where two tons to the acre were used, three-quarters of it gave no increased returns.

Light liming is to be recommended when it is needed chiefly to supply lime as a plant food, for which heavy liming is needless. Even where heavy applications are needed for improving the physical condition of the soil, heavier liming than is necessary should be avoided because the losses by natural processes are proportional to the amount of lime added.

Another advantage of light liming is that it fits in with the other farm work more easily than heavy liming, since the latter is such a big job that it cannot be done at any time when regular farm work is pressing.

Kind of lime to be used.—On sandy soils which are liable to be deficient in organic matter, one of the carbonate forms is preferable to any of the caustic forms of lime. For heavy soils on which lime is valuable chiefly as a means of improving the physical conditions caustic lime will give a quicker response, owing to its greater solubility in water. Aside from these specific recommendations, the choice of the kind of lime to use may depend on economic conditions chiefly. It would seem best to use that form of lime which will supply the most actual lime, that is, the greatest neutralizing power, for a dollar. This will depend on (*a*) chemical equivalent, that is, actual lime supplied, (*b*) cost of a ton or other unit, (*c*) freight cost, (*d*) cost of hauling and application.

Lyon and Buckman* give the following example to illustrate the point:

Suppose slaked lime, 70 per cent CaO, sells at $8.00 a ton, and ground limestone, 50 per cent CaO, costs $4.50 a ton, and the freight charge is $3.00 a ton, hauling and spreading $1.00 a ton.

Then 1 ton of slaked lime would cost $8 + $3 + $1 = $12 on the soil.

To furnish the same amount of actual lime, CaO, in the form of the ground limestone, would require 1.4 tons, which would cost $6.30 + $4.20 + $1.40 = $11.90. In this example, the difference between the two forms is slight. Lower cost of freight or hauling would give the ground limestone still further advantage, while increasing these charges would make it cheaper to use the slaked lime.

Evidently, every farmer should calculate for himself which will be the cheaper form of lime, giving due consideration to each of the separate items of cost.

VII. LOCALITIES IN CALIFORNIA WHERE LIME IS LIKELY TO BE BENEFICIAL

A large proportion of California soils contain enough lime so that further applications are not likely to be advantageous. Relatively, only a small portion of our soils may be called sour. Heavy clay or adobe soils, however, are usually improved in physical character by liming.

Lime is more or less helpful in parts of the northern coast counties and to some extent south of San Francisco Bay, in a good deal of the Sierra Nevada foothills on the east side of the great interior valley, and in various places throughout the valley. South of the Tehachapi, lime is not usually needed.

VIII. STATE INSPECTION AND ANALYSIS OF LIME MATERIALS

Some years ago, much very inferior lime was sold for the price of good material. To protect the public in this matter, the sale of agricultural minerals, including all forms of lime, was placed in charge of the State Fertilizer Control in 1923. That office now makes regular inspections and analyses of minerals offered for sale, and takes care that the dealers shall supply goods of the quality they guarantee. Any farmer may have his lime analyzed by the Fertilizer Control at small cost, and so may be sure of the quality of the lime he is buying. Application should be made to the Bureau of Chemistry, State Department of Agriculture, at Sacramento.

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* Lyon, T. L., and H. O. Buckman, The nature and properties of soils, p. 368. (Macmillan Company, New York, 1922.)

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